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ULTRASONIC INSPECTION OF TUNGSTEN ROUND ROBIN BILLETS, PHASE III

BY

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ULTRASONIC INSPECTION OF TUNGSTEN ROUND ROBIN BILLETS, PHASE III

This Laboratory has completed Phase III of the Tungsten Billet Round Robin. This is a reinspection, after silver infiltration, of the Phase I billets AG2230 and AG2231 (now numbered AG2230A and AG2231A).

This report covers the following subjects:

1. Immersed and contact inspection at normal incidence; chord shot (shear wave) immersed only.
2. Longitudinal velocity of sound measurements using contact thru-ray technique.
3. Effect of grain size on transducer frequency.
4. A preferred inspection procedure utilizing automatic compensation of gain for defect depth.

1. Ultrasonic Results of Defects Noted.

All results reported below were obtained using the immersion method at a frequency of 5 mc. The transducer used was a 0.5 inch diameter Branson "Z" (tuned) with a water path of 3 inches. The equipment used was the Immerscope with provision for automatic scanning and recording. The Immerscope sensitivity was adjusted using the AGC silver infiltrated reference standard, the reference holes put in the billets, and the NRL reference standard made by Firth Sterling. The sensitivity control was adjusted for 100% (Full Scale) reflected signal amplitude from the #3 flat bottom hole (FBH). The recorder firing level was adjusted to record a signal amplitude of 50% of full scale and greater which appeared in thegate. The equipment sensitivity and recorder firing level were rechecked after each test to insure identical inspection conditions. The Sensitivity Time Control (STC) was used for all inspections. This is explained in detail in Section 4.

(A) Billet AG 2230A

Normal Incidence - Immersed

In order to eliminate the necessity of continuous monitoring of the equipment to determine defect depth, the gating and recording circuit were adjusted in increments of one inch. As can be seen in Figure 1, much time was saved since the majority of the "defects" appeared at a depth of 4 to 5 inches.

The billet was also inspected bottom up. The only defects found were at a depth of 3.5 to 5 inches from the bottom. Figure 2 is a recording of the various defect areas. An interesting feature of the test results is the amount of "edge effect" which is very obvious in Figures 1 and 2. This is due to a slight machined bevel which was on both the inner and outer diameters of both ends of the billet. Actually, we did use the electrician's tape technique which we described in the Phase I Report[1] but the bevel introduced some additional edge effect.

[1] NRL Technical Memo #214

Shear Wave (Chord Shot) - Immersed

A shear wave chord shot of the untapered portion of the cylindrical section was made in both a clockwise and counter-clockwise direction. The angle of incidence used was 20° giving a shear wave of 34° into the billet. This was based on the measured shear wave velocity of 0.098 in/μsec of past silver-infiltrated samples of equivalent density by the same manufacturer.

Radial Shot - Immersed

A radial inspection was performed on the untapered section of the billet. No defects other than the drilled holes were found. No attempt was made to inspect the tapered section of the billet either radially or by chord shot, since this would involve a very complicated and lengthy inspection procedure.

Normal Incidence - Contact

Contact testing at normal incidence only was employed to see if the automated inspection data could be correlated. Correlation was obtained but with the same difficulties reported in our Phase I report.

(B) Billet AG 2231A

Normal Incidence - Immersed

This billet was inspected in a manner similar to that of AG 2230A. Namely, top up and bottom up. Figures 3 and 4 show the actual inspection results. To save time, the flaw gate was set to record all defects of sufficient amplitude from a depth of 0.5 inches to 5.0 inches, rather than in depth increments of one inch. In addition, binder head screws were taped around the circumference of the billet at 30° increments to obtain a more accurate location of "defective" areas. These can be seen in Figures 3 and 4 as circular outlines. This is a much more accurate means of flaw location on round billets. If one had a number of these billets to inspect, a hinged prefabricated plastic appliance could be made to fit around the circumference of the billet. This would not only facilitate flaw location, but it would also help reduce "edge effect".

Shear Wave (Chord Shot) - Immersed

In the Phase I report, we reported two cracks located at approximately 0° and 180°. Apparently, the 0° reference has been changed, because now the two cracks were found at approximately 90° and 270°. In addition to the two cracks, there were two distinct bands of "crud" located approximately one inch and four inches down from the top surface. The term "crud" is used because we can't classify the observed oscilloscope indications as discrete "defects". The indications are multiple, in nature and of varying amplitudes. They appear at the same depth each time as layers of many small defects. The indications are similar to those obtained from small multiple inclusions, porous areas, variable grain size, or variable density areas. Very seldom is even one of the individual indications equivalent to a #3 FBH.

Normal Incidence - Contact

Contact testing of this billet correlated the data we obtained using the immersion method. The two "bands" could also be detected.

(C) Ultrasonic Results: Defects Noted

BILLET	ANGLE OF INCIDENCE	DEFECT LOCATION		
		DEPTH (in inches from top surface)	RADIUS (in inches)	ANGLE IN DEGREES
AG2230A	Normal	4.75	2.5	10°
	"	3.6	2.5	15°
	"	2.5	3.25	50°
	20° Chord	6.0	3.5	168°
	Normal	Defect areas too numerous to tabulate. Refer to Figures 1 and 2		
AG2231A	Normal	Defect areas too numerous to tabulate. Refer to Figures 3 and 4.		
	20° Chord	2 cracks at approximately 90° and 270° extending radially from I.D. in varying amounts. Also extending axially from top to bottom surface.		
	20° Chord	Band of "crud" varying in width from 0.5 inches to 1.5 inches, 1 inch down from the top surface. In addition, there were many small areas too numerous to tabulate.		

(D) Discussion of Inspection Results

The only defects which we found equivalent to or greater than a #5 FBH were the two cracks in AG2231A. Defects in AG2230A actually found to be equivalent to a #3 FBH were located at 10, 150, 165, 180, 210, 220, and 290 degrees. These were found shooting at normal incidence, top up. (Figure 1). All other defects were smaller in amplitude but large enough to record.

Several photographs of the observed oscillograms were taken to clarify statements made in this report. Keep in mind that the Immerscope sensitivity was set to obtain 100% signal amplitude from a #3 FBH, but the recording level was set to record at a 50% amplitude level. This is necessary in order to obtain recordings of marginal defects. Figure 5 shows an area at 15° in AG2230A. Two distinct defects can be seen at depths of 3.6 and 4.8 inches. Since both defects are less than 50% amplitude, neither would be recorded. Now refer to Figure 6 - on the same scan at an angle of 10°, one defect is increasing in amplitude as the other

is decreasing. The larger amplitude signal is now recording. If an indexing increment of 0.050 inches or less is used the defect will clearly show on the recording, but if larger indexing increments are used it could be easily missed. A good "rule of thumb" is that the smallest desired area to be detected, should be recorded on a minimum of three successive index increments.

Since the word "crud" is not very scientific, Figure 7 will possibly help define it. This is an oscillogram of an area in AG2230A at 210°. Note the varying amplitude and baseline noise.

Figure 8 shows a real nice "defect" in AG2230A at 140° at a depth of 3.5 inches. It is really an accidental "booby trap" which can throw an inspector behind schedule. This was an air bubble on the O.D. of the billet. Only a very small section of the 0.5 inch transducer was beyond the edge of the billet. By the way, it was equivalent to a #5 FBH.

2. Longitudinal Velocity of Sound Measurements

The longitudinal velocity of the AGC Reference Standard, and the two billets was measured using the contact thru-ray method at a frequency of 5 mc. There was no noticeable change in velocity thru 360° rotation of each billet. The following velocity values were obtained. The measurement accuracy is better than 1%.

Material	V_L (in/sec)
AGC Reference Standard	0.188
AG2230A	0.189
AG2231A	0.189

The phase I radiographic results reported by AGC, NAD, MFDL, and NOL indicated that the two billets contained areas of low density. We have been unable to determine density variations in either the uninfiltrated nor the infiltrated condition by longitudinal velocity measurements. This verifies Appendix II of the Phase I Report. It also shows the need for radiography, if variable density is cause for rejection.

3. Grain Size Determination

This Laboratory did not attempt to make a grain size determination on any of the billets used in the Round Robin. We do not feel that these billets are representative of current manufacturer's production capabilities.

Grain size[2] is determined by measuring the ultrasonic attenuation at various frequencies in the range of 1 mc to 25 mc. The resultant measurements are of little value unless a set of reference standards are available for comparison. Since the attenuation would be affected by porosity, inclusions, uninfiltrated areas, silver-rich areas, surface finish, as well as grain size, there would be no nondestructive method of verifying the ultrasonic results.

[2] J. B. Morgan, "Ultrasonic Testing Standards for Steel Products", Nondestructive Testing, 20, #3, 167, (1962)

4. A Preferred Inspection Procedure

In all our past inspections of the round robin billets, we used the conventional method - gain set for 100% reflected signal amplitude from a #3 FBH located at the maximum depth of inspection. If the material contains many defects, the inspector is required to recheck each defect indication, taking into consideration both size and depth. This requires a complete set of reference standards. Not only is this time consuming, but requires repeated readjustment of both the equipment gain and the transducer, thereby increasing the probability of errors and increasing inspection time.

The stepped reference standard which was supplied by [illegible] for this particular phase of the Round Robin enabled us to try out the automatic compensation of gain for distance depth method of inspection. The Reflectoscope can be adjusted to perform such an inspection by utilizing the "Sensitivity Time Control" (STC). Not all ultrasonic test instruments have this capability.

We performed several tests to ascertain the reliability and applicability of this test method to the inspection of tungsten billets. They are as follows:

a. Three aluminum test blocks were made at this laboratory. Each test block was 4.25 inches in diameter and contained a 0.5 inch deep #3 FBH in the center at one end. The heights of the blocks were 1.5, 3.5 and 6.5 inches. The top and bottom surfaces were maintained parallel and the surface finish was equivalent to that of the infiltrated tungsten billets.

b. Reflectoscope Sensitivity and STC controls were adjusted to give 100% reflected signal amplitude from the #3 FBH in both the 1.5 and 6.5 inch test blocks maintaining a constant water path of 4 inches. The transducer was then located over the 3.5 inch test block (water path of 3 inches) and no appreciable change in reflected signal amplitude was noted. See Figures 9, 10, and 11. This shows that "STC" corrects linearly.

The same method was employed to check the Sonoray which was used in contact testing. It has a similar circuit which is called "Time Corrected Gain" (TCG).

c. The effect of waterpath length on sensitivity using "STC" was investigated. We found that unless a constant water path is maintained while adjusting the equipment and also during the inspection, the method is invalid. This can be seen by comparing Figure 12 with Figure 9, and Figure 13 with Figure 10. For this reason, the infiltrated AGC reference standard is not desirable for immersion testing but would be adequate for contact testing. We recommend a stepped reference standard 4" wide by 9" long with each step being 3" x 4" and having a depth of 1, 3.5 and 6.5 inches respectively. The flat bottom holes should be drilled 0.5 inches deep on the underside of each step; each step to contain a #3, #5 and #8 FBH with 1 inch spacings between holes aligned across the width of the block. See Figure 16. With this type of reference standard, the transducer to top surface distance would be constant. This was not so for the AGC reference standard.

d. The advantage of using "STC" can readily be seen when a comparison of Figures 14 and 15 is made. The figure 14 oscillogram shows a series of defects at a depth of 1 to 2 inches in the AGC reference standard when we had adjusted our equipment for 100% reflected signal amplitude of the #3 FBH, 5 inches from the top surface. The Figure 15 oscillogram was taken with the "STC" in the circuit. Notice that the "defects" which in Figure 14 appeared to be equivalent to a #3 FBH no longer exist.

We carried our tests one step further to ascertain reliability and repeatability of this method. We found that each of us could set up the "STC" independently and obtain the same dial settings. Also, that the Immerscope gain was stable enough to merely reset the equipment dials to the settings we obtained from the initial adjustment. We checked this repeatability against the reference standard several times each day for a period of five days with no noticeable change in dial settings.

d. Since chord shots (shear wave) are necessary in this program, it would be desireable to have a reference standard for this particular inspection. Throughout this round robin program, we have been unable to really justify the equipment gain setting we used for the chord shots, because the drilled holes were never in the same location for each billet. For this reason we are not certain whether we have been over-inspecting or under-inspecting.

Also, we found that, when inspecting axially at normal incidence, the billet should be inspected with both "top up" and "bottom up". Defects were found which from one axial direction were much smaller than a #3 FBH. This was with STC. It may indicate that defects have a different shape as viewed from top and bottom.

Summary

1. We are able to detect defects somewhat smaller than the area of a #3 FBH at a depth of 6 inches in silver infiltrated tungsten.

2. No significant change in sound velocity was observed.

3. Grain size determination by an ultrasonic attenuation measurement in large billets is possible but too many other variables can effect the data obtained.

4. Adequate reference standards are required.

5. Automatic compensation of gain for defect depth in immersion inspection system is superior to any other ultrasonic method.

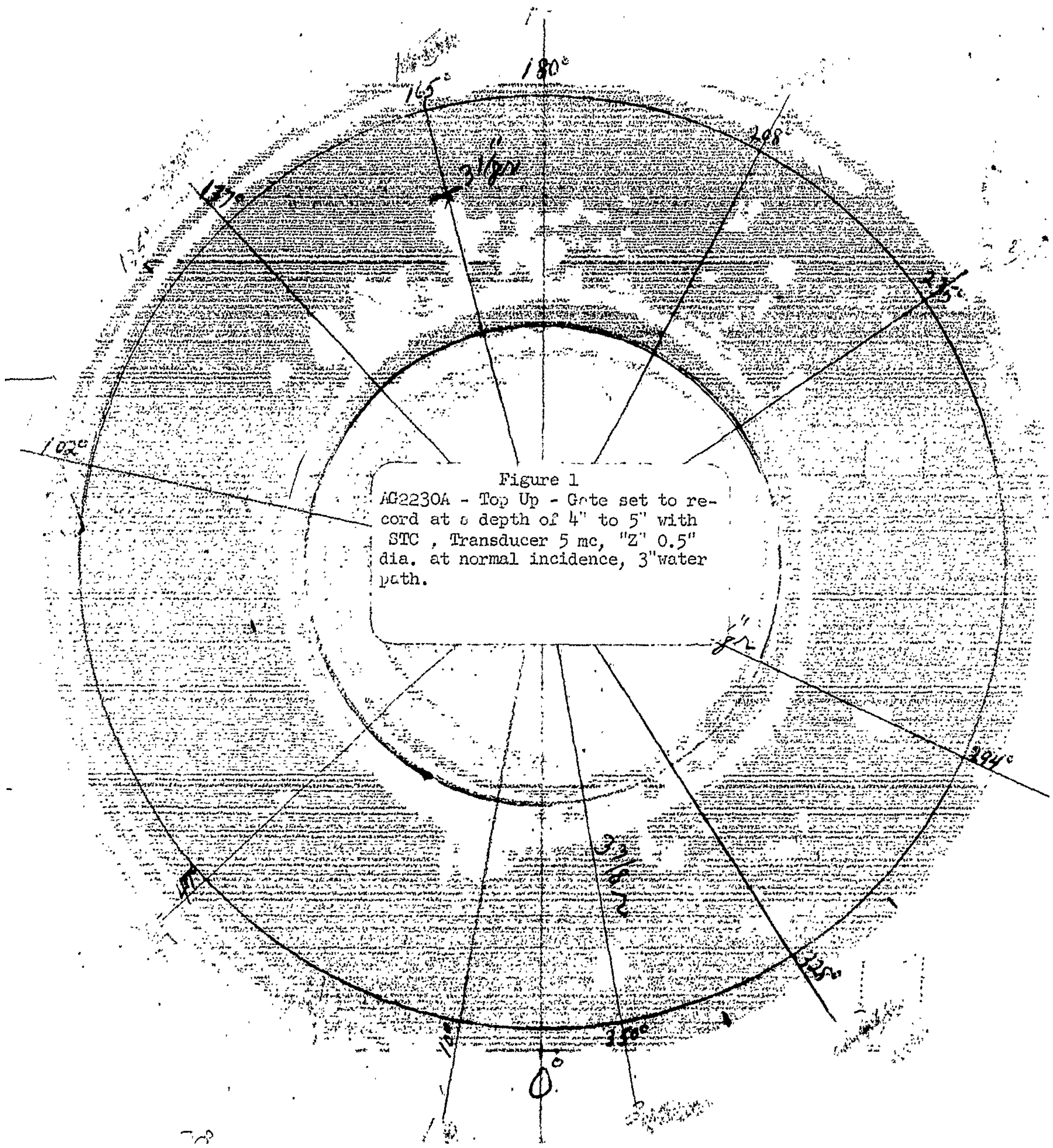


Figure 1
AG2230A - Top Up - Gate set to record at a depth of 4" to 5" with STC , Transducer 5 mc, "Z" 0.5" dia. at normal incidence, 3"water path.

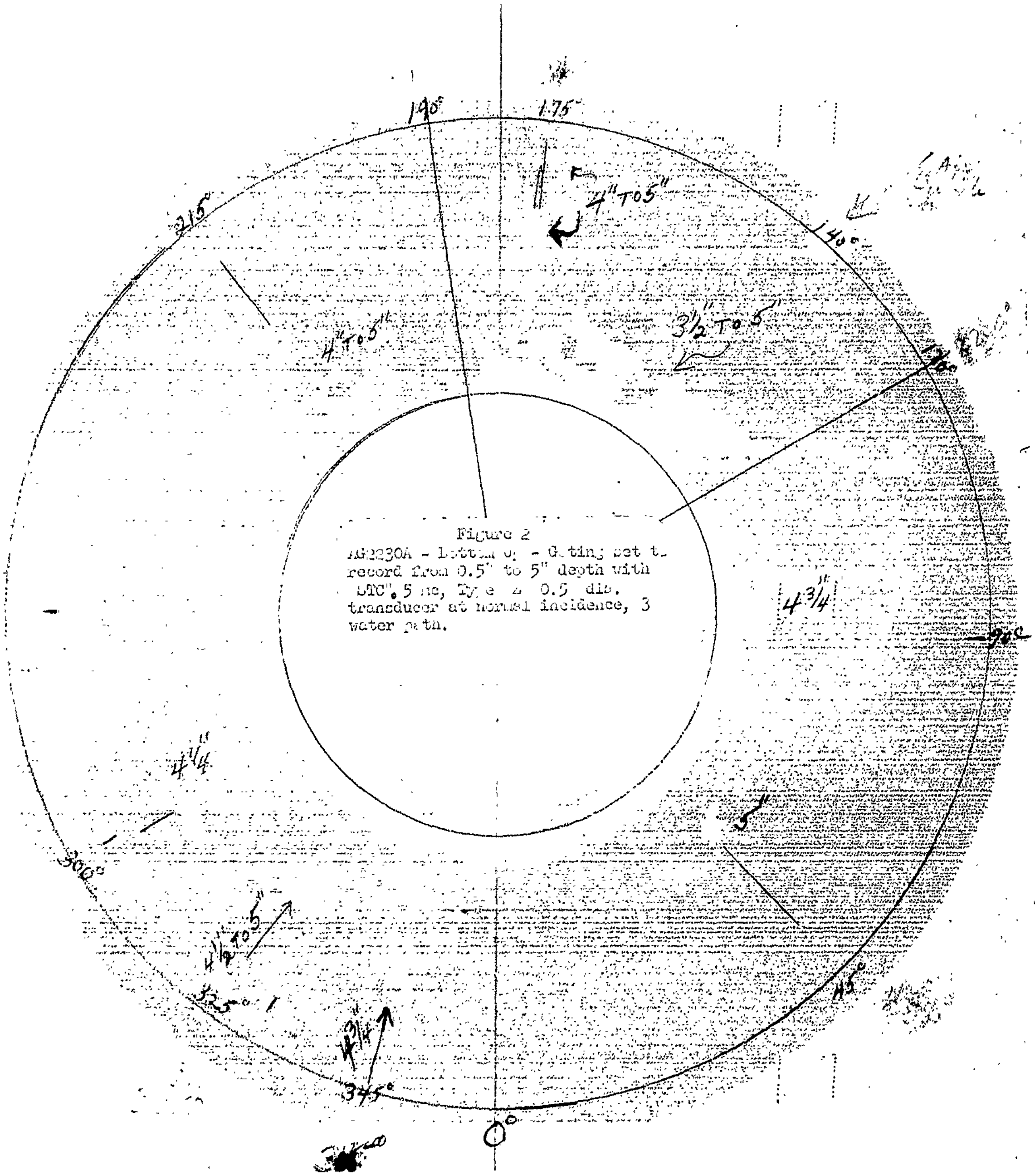
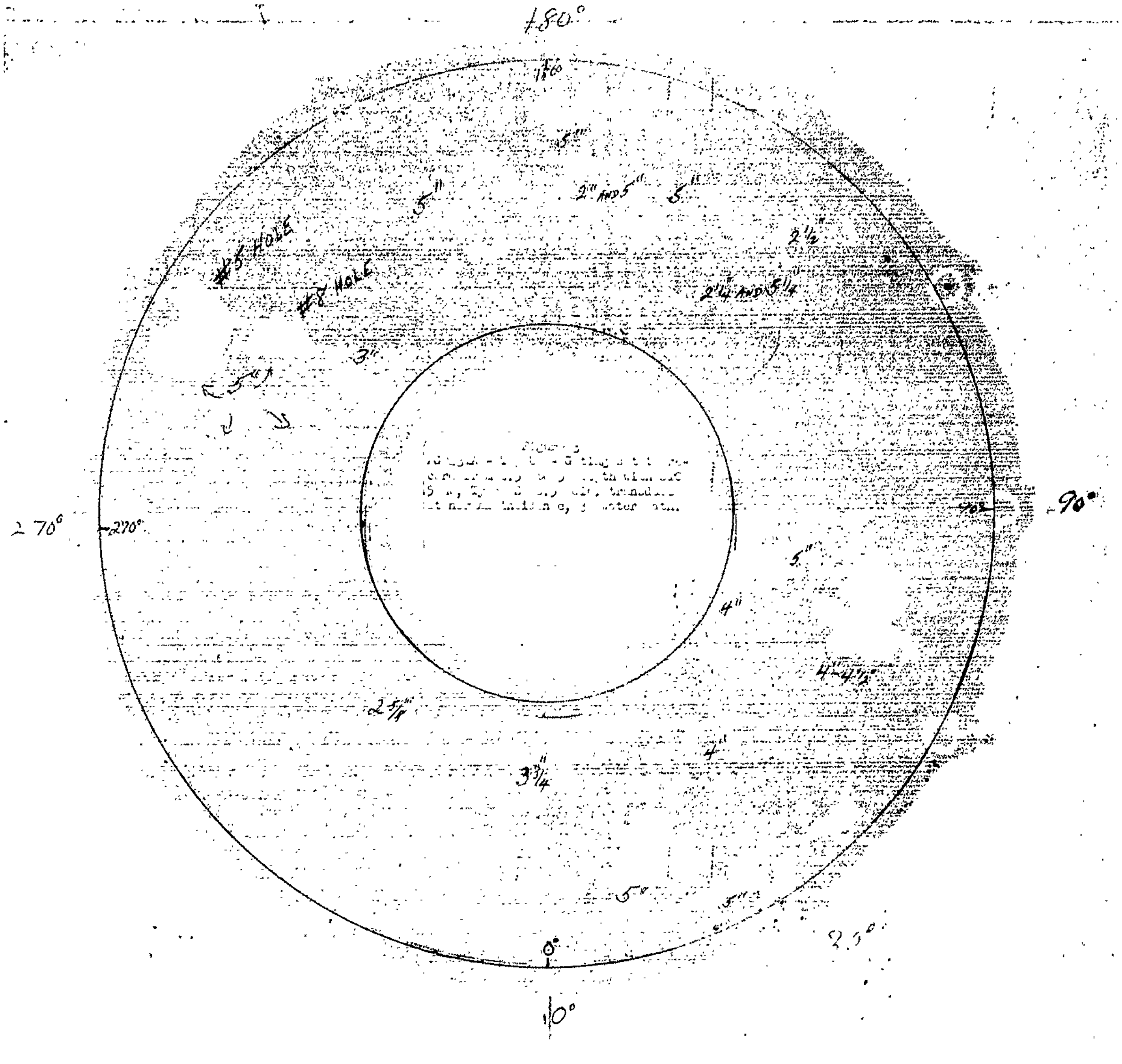


Figure 2
AG2230A - Bottom up - Gating set to record from 0.5" to 5" depth with STC, 5 mc, Type Z 0.5 dia. transducer at normal incidence, 3 water path.



180°
5"
2" AND 5"
5"
2½"
#8 HOLE
#8 HOLE
2¼" AND 5¼"
3"
5"
270°
90°
5"
4"
4-4½"
3¾"
4
5"
0°

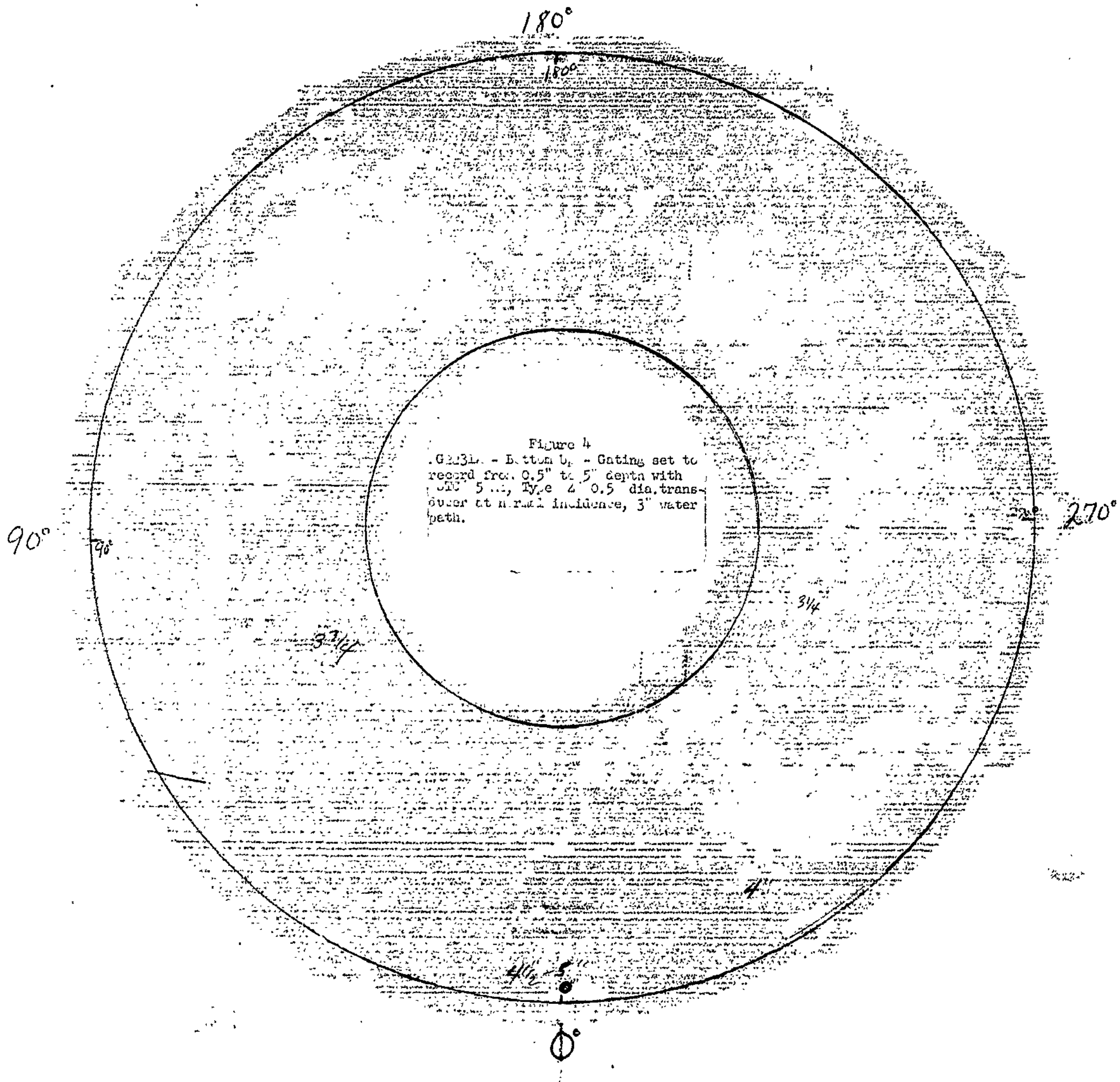


Figure 4
.G223L - Bottom Up - Gating set to record from 0.5" to 5" depth with SIC 5 Mc, Type 4 0.5 dia. transducer at normal incidence, 3" water path.

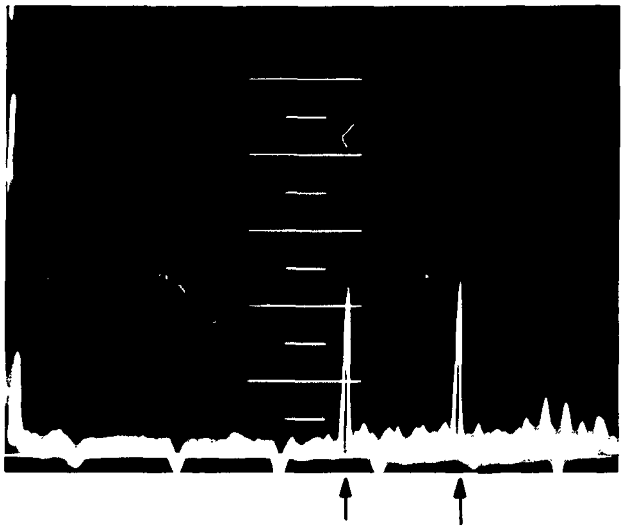


Fig 5 - Defects in AG2230A at 15° at depth of 3.6" and 4.8"

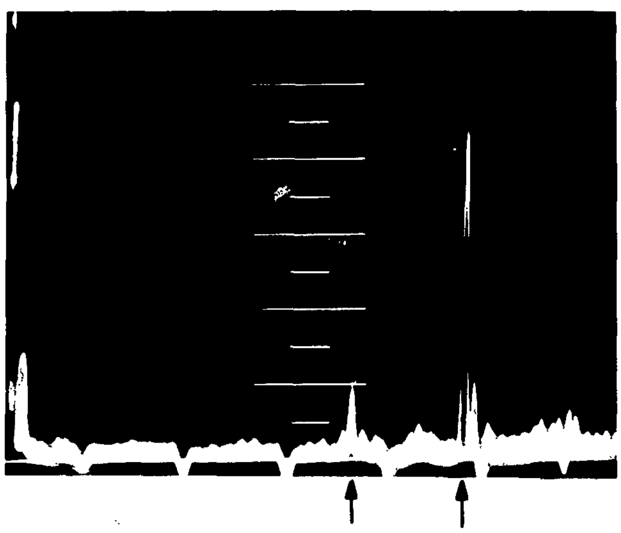


Fig 6 - Same defects as above but at 10°

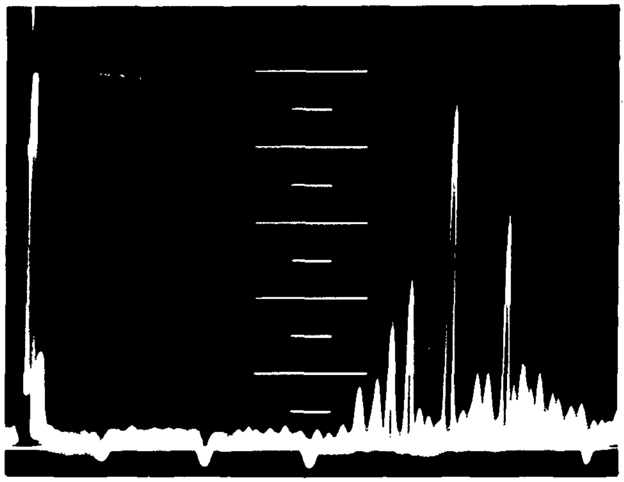


Fig 7 - Area in AG2230A at 210°

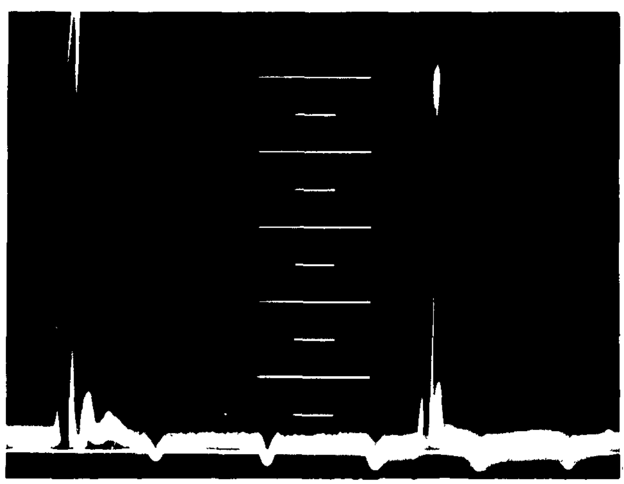


Fig 8 - Air bubble at 140° on AG2230A

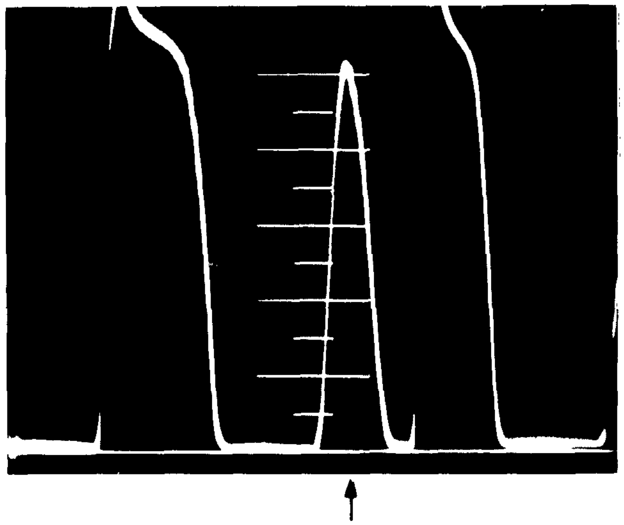


Fig 9 - #3 FBH 1" down in Al, 4" water path, - using Immerscope "STC"

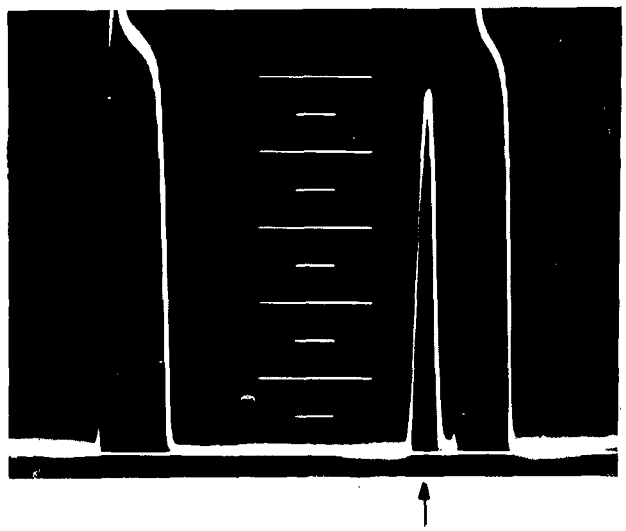


Fig 10 - #3 FBH 3" down in Al, 4" water path, - using Immerscope "STC"

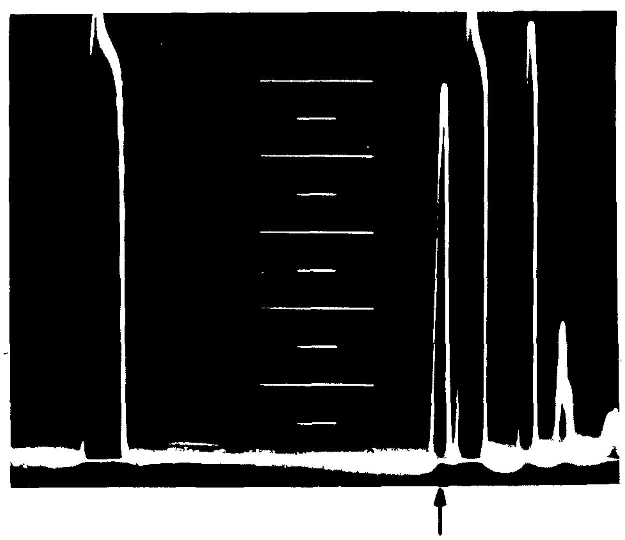


Fig 11 - #3 FBH 6" down in Al, 4" water path - using Immerscope "STC"

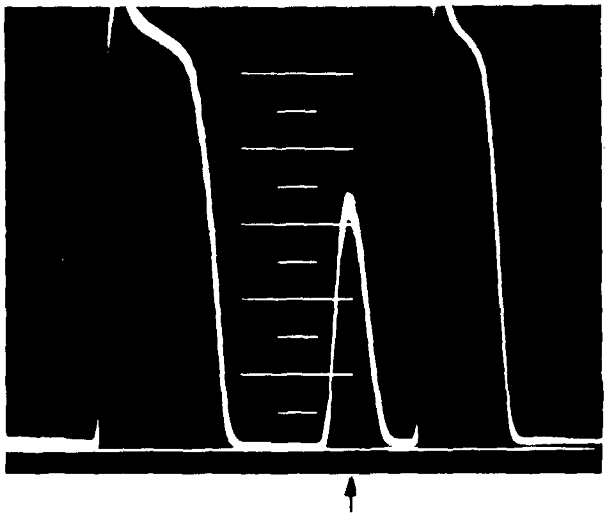


Fig 12 - #3 FBH 1" down in Al, 9" water path, using Immerscope "STC"

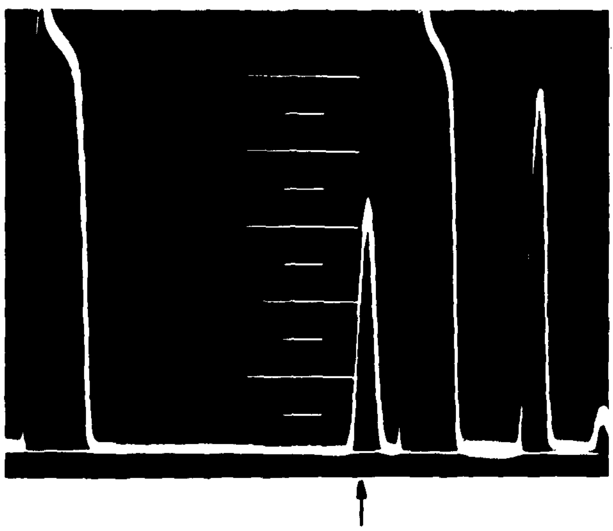


Fig 13 - #3 FBH 3" down in Al, 7" water path, using Immerscope "STC"

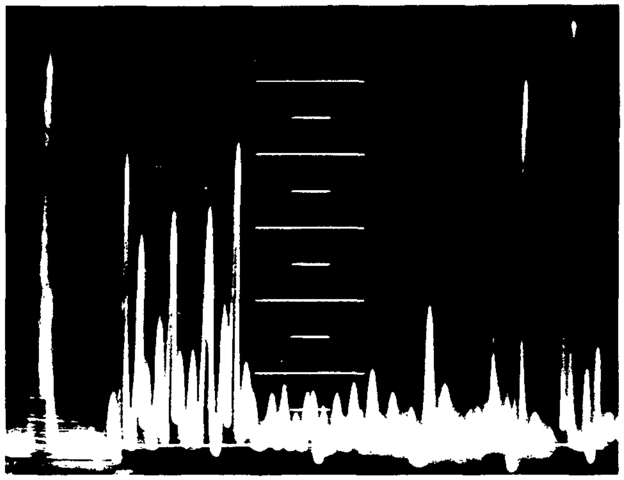


Fig 14 - #3 FBH 5" down in AGC Reference Standard, Immerscope with no "STC"

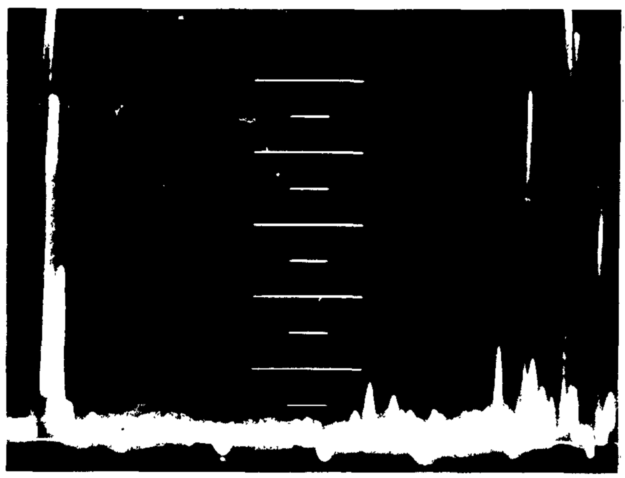


Fig 15 - #3 FBH 5" down in AGC Reference Standard, Immerscope with "STC"

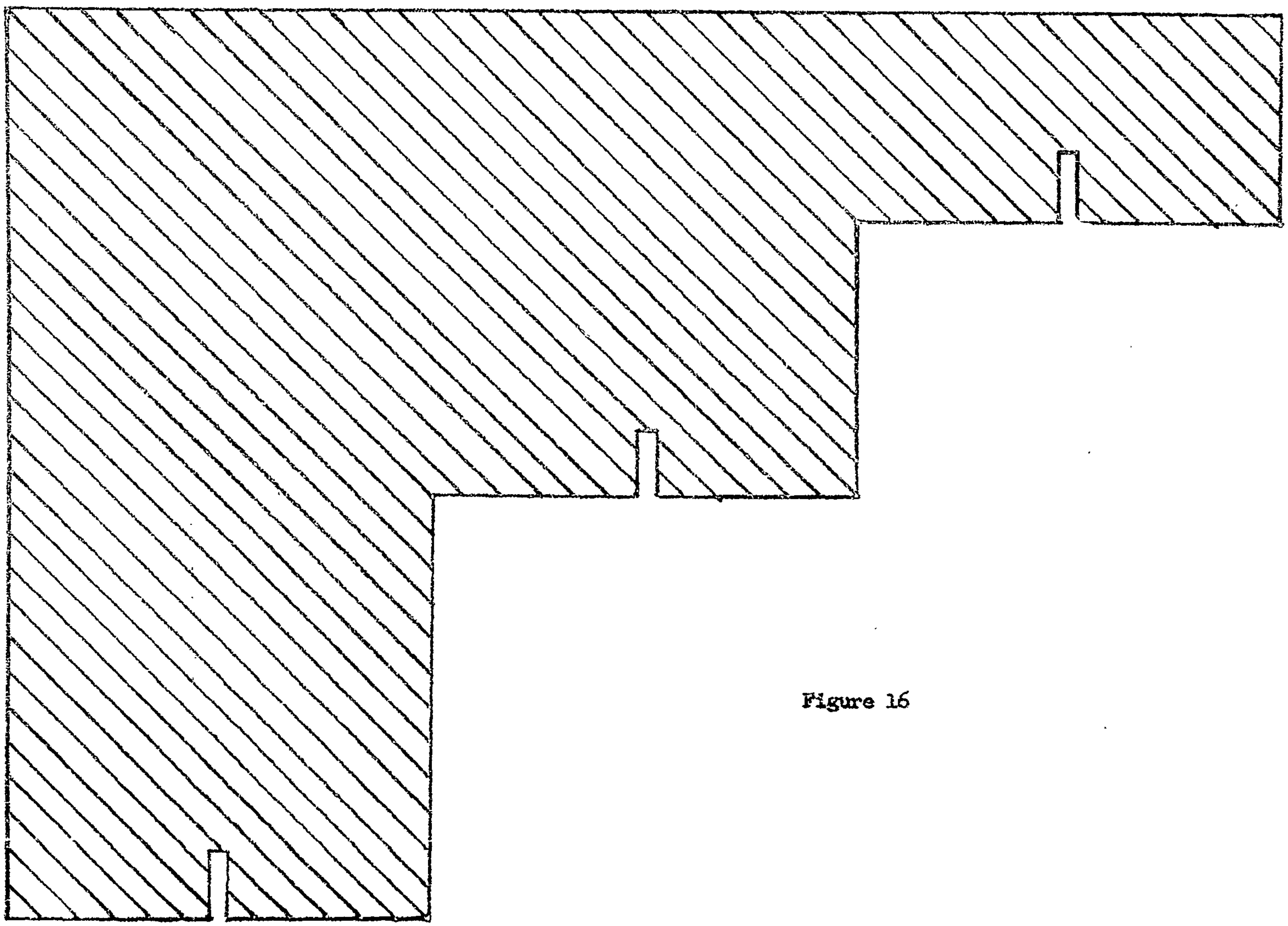


Figure 16